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Effects of Initial Parameters on the Development of Cube Texture during Recrystallization of Copper

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Abstract. A series of oxygen free high conductivity copper samples with different initial grain sizes, cold rolling conditions and storage times as well as slightly different impurity contents was used to investigate the effects of these initial parameters on the development of cube texture during recrystallization. For rolling reductions of 90% and 95%, cube textures with volume fractions between 3% and 50% were observed. Higher rolling reduction led to a stronger cube texture. Cube texture development is very sensitive to the initial grain size before rolling. In general, fine grained material gives a strong cube texture after recrystallization, and the requirement on fineness of the grain size may vary for materials with different purity. Large sample widening during rolling can largely inhibit the development of cube texture after recrystallization. Neither storage time, nor the slight change in impurity content had large effects in the present investigation.

Introduction

Cube texture development during recrystallization has been a research focus for a long time (cf. [1]), and it has been discussed at many texture conferences, mainly because of its technical importance, such as its effects on the deep drawing process and, more recently, the development of good superconductor substrates. It is also a key point for understanding recrystallization mechanisms. Copper is a good material for cube texture studies since it can develop a strong cube texture during recrystallization after large rolling reductions. The strength of the cube texture, however, is sensitive to various parameters including purity, initial grain size, strain, etc [2]. The aim of the present work is to investigate the effects of a series of initial sample and rolling conditions on the strength of the cube texture after recrystallization.

Experimental

The material investigated was a commercial oxygen free high conductivity (OFHC) copper, in which the main impurities were 0.002% Ni, 0.002% Mg, and 0.002% Al. Reference material (referred as sample 1) was prepared by heat treatment at 650 °C for 2 hours. The grain size was 77 µm. The initial texture was weak, for example the volume fraction of the cube texture component (determined as described below) was only 3.5%. This material was cold rolled to 90% and 95% reduction in thickness. Oil was used as lubricant to reduce surface friction. The rolling was done with homogeneous rolling conditions, with the ratio of contact length over thickness kept between 1 and 4.5 in accordance with recommendations [3]. For comparison purposes, several other samples were prepared. They are described below and summarized in Table 1.

Electron backscatter diffraction (EBSD) was used to characterize the recrystallized microstructure and texture. Orientations were measured on regular grids of 300 x 300 μm^2 with a step size of 1 µm on the transversal plane containing the rolling and normal direction. For calculating the volume fraction of the cube texture component a deviation of 15° from the ideal cube orientation was allowed. Pole figures as presented in Fig. 1 were calculated from the orientation data. The contours were achieved by smoothing the individual measured orientations with Gaussian distributions with a half width of 10°.

Table 1 List of samples with various initial parameters. The volume fraction of the cube component before rolling and after recrystallization was determined by allowing a 15° deviation from the ideal cube orientation.

Sample	Description	Volume fraction of cube component before rolling	Volume fraction of cube component after recrystallization	
			90% cr	95% cr
1	Initial grain size 77 µm, weak initial texture Main impurities: 0.002% Ni, 0.002% Mg, and 0.002% Al	3.5%	5.6%	14.1%
2	Same initial conditions as sample 1 Stored at room temperature for 2 years after cold rolling	3.5%	--	13.5%
3	Initial grain size 78 µm, weak initial cube texture Main impurities: 0.003% Fe, 0.002% Ni, 0.002% Mg, 0.003% Al	15.6%	3.9%	--
4	Same chemical composition as sample 1 Initial grain size 22 µm, very weak initial texture	2.0%	50.3%	--
5	Same initial conditions as sample 4 40% sample widening during cold rolling	2.0%	8.7%	--

Results and discussion

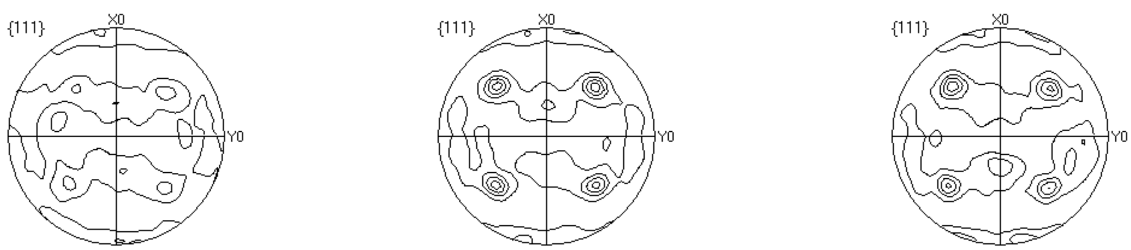
The 90% and 95% cold rolled reference materials (sample 1) were annealed at 230 °C for 1 hour, after which the samples were fully recrystallized without obvious grain growth. In the 90% reduction sample the volume fraction of the cube component was 5.6% after recrystallization, while in the 95% reduction sample it increased to 14.1%. The pole figures in Fig. 1a and Fig. 1b illustrate the recrystallization texture. In both cases a weak cube texture component was obtained, while some rolling texture components are retained.

Sample 2 had the same chemical composition, initial grain size and texture as sample 1. The sample was cold rolled to 95%, and kept at room temperature for 2 years. It was then annealed at 230 °C for 1 hour. The volume fraction of cube component after recrystallization was 13.5%. The recrystallization texture of sample 2 (Fig. 1c) was similar to that of sample 1 (Fig. 1b). The effect of long time storage in the deformed state on the cube texture development was observed to be very limited.

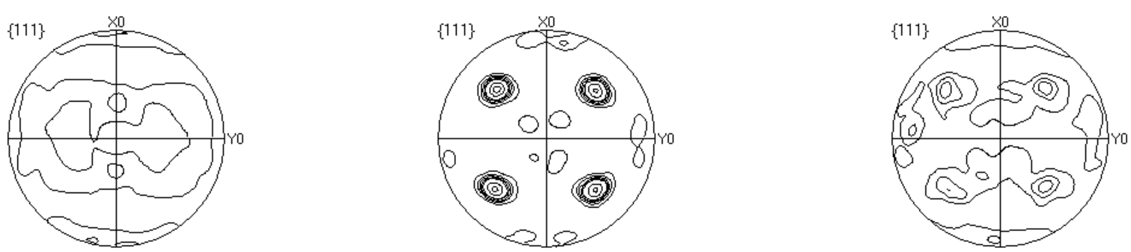
Sample 3 had impurity contents slightly different from sample 1. The main impurities in sample 3 were 0.003% Fe, 0.002% Ni, 0.002% Mg, and 0.003% Al. The initial grain size of sample 3 was 78 µm, and there was a weak cube texture (15.6% volume fraction) in the initial material. After cold rolling to 90% and annealing at 230 °C for 4 hours, a volume fraction of 3.9% was obtained for the cube texture component – even lower than that for sample 1 despite the stronger cube texture in the initial state (which is expected to give rise to a stronger cube texture after recrystallization [4]). Fig. 1d illustrates the texture of sample 3. It was similar to Fig. 1a, except that the cube component was slightly weaker than for sample 1. Neither the different initial texture, nor the different impurity contents in sample 1 and sample 3 did have a strong effect on the cube texture development during recrystallization. It should be noticed, however, that sample 3 was recrystallized to 95% only even after 4 hours annealing at 230 °C, while sample 1 reached the same fraction of recrystallization in 20 minutes. The recrystallization process was much slower in sample 3 - as expected from the larger impurity content [2].

The initial material of sample 1 was cold rolled to 50% and annealed at 450 °C for 1 hour (sample 4). The grain size was thereby reduced to 22 µm, while the texture was still very weak (2.0% volume fraction of cube texture). Sample 4 was cold rolled to 90% reduction and annealed at 230 °C for 1 hour. After recrystallization, 50.3% cube component was obtained. Fig. 1e illustrates that the recrystallization texture of sample 4 is composed of a strong cube texture with a minor cube twin component. The cube texture development during recrystallization was thus for the present copper material found to be very sensitive to the initial grain size.

Similar results have been reported earlier [1]. For instance, Ryde et al [5] have observed that OFHC copper of 15 µm grain size gives a strong recrystallized cube texture, while the same material with a grain size of 50 µm leads to a weak retained rolling texture; both samples were cold rolled to 93% and recrystallized. They found that the initial grain size for the transition of the recrystallization texture from cube texture to non-cube texture was at about 35 µm. However, there are also several reports on the development of strong recrystallized cube texture with initial grain sizes of 50 µm to 100 µm after about 90% cold rolling [6,7]. The different dependence of the cube texture on the initial grain size is most possibly caused by the different sample impurity contents.



a) maximum density: 2.5 b) maximum density: 5.7 c) maximum density: 5.3



d) maximum density: 2.6 e) maximum density: 23.6 f) maximum density: 5.1

Fig.1 {111} pole figures of different recrystallized samples: a) sample 1; 90% reduction, b) sample 1; 95% reduction, c) sample 2; 95% reduction, d) sample 3; 90% reduction, e) sample 4; 90% reduction, f) sample 5; 90% reduction. Contour levels (1,2,3,4,5,10,15,20 of multiples of uniform density) obtained by smoothing with Gaussian distribution of a 10° half width.

Sample 5 had the same initial conditions as sample 4, but smaller initial sample width. After cold rolling to 90% reduction with the same rolling schedule as sample 4, sample 5 showed a relative widening of 40% after rolling, while the widening for sample 4 was only 8%. After annealing at 230 °C for 1 hour, sample 5 developed 8.7% cube component. The recrystallization texture is illustrated in Fig. 1f. The cube texture development was observed to be largely inhibited by the sample widening.

The effect of sample widening on the development of cube texture was also investigated by Hammelrath et al [8]. By comparing a cold rolled sample with a channel-die compressed sample (without widening), it was found that a cold rolled sample with a moderate sample widening (around 10%) can give a sharper and stronger cube texture after recrystallization. The present study however shows that a large sample widening of 40% is unfavorable for cube texture development in accordance with observations on aluminum [9].

Conclusions and outlook

Effects of different initial parameters on the cube recrystallization texture were investigated, and in agreement with earlier reports. It was found that the initial grain size and sample widening during rolling had very significant effects. The storage time and sample purity did not affect the cube texture development in the investigated samples. To get a more complete understanding of why and how initial grain size and sample widening influence the cube texture development, a systematic study of the recrystallization kinetics of different samples would be required.

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